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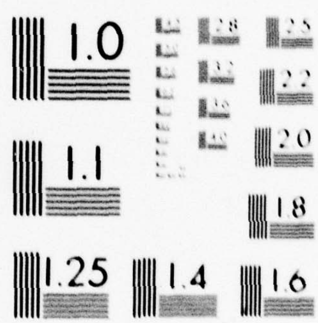

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QUASI-THREE-DIMENSIONAL DISPLAY OF INFRARED RADAR IMAGES USING RANGE/INTENSITY COLOR MAPPING

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TECHNICAL NOTE 1978-44

6 DECEMBER 1978

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ABSTRACT

By mapping range information into different hues and intensity information into different apparent brightness levels of each hue on a color display, a three-dimensional quality can be imparted to infrared radar images. A computer algorithm for implementing this range/intensity color mapping is described and several infrared radar images demonstrating the technique are presented. Possible improvements to the current algorithm and areas requiring additional study are also discussed.

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I. Introduction

Recent advances in CO_2 laser and 10.6 μm heterodyne detector technology make possible the development of compact imaging infrared radar systems.[1] Among the functions envisioned for such systems are terrain avoidance, obstacle avoidance, and bad weather landing.[2] The ability to display a three-dimensional image of the scene is extremely useful in accomplishing either of these functions. Infrared radars are capable of providing both range and angular information as well as intensity information. In principle, therefore, a three-dimensional representation of the scene is possible. In this paper we discuss the use of range/intensity color mapping to produce quasi-three-dimensional radar images. A computer algorithm is described which performs the mappings necessary for obtaining a quasi-three-dimensional image on an image processing system with a pseudocolor display and several suitably processed infrared radar images are presented. Finally, several possible modifications of the technique are outlined and areas requiring additional investigation are discussed.

Range/intensity color mapping involves quantizing the range information of an image into a number of bins and assigning a different hue to each range bin. By using a number of visually distinct colors of each hue (varying only in brightness and saturation) the appropriately quantized intensity information may also be encoded. Thus, on a color display, objects at different ranges have different hues while objects at the same range but differing in intensity have different apparent brightness levels of the appropriate hue.

For example, consider an image containing pixels with digital intensity values between 0 and 12 and digital range values between 0 and 11. A simple range/intensity color mapping for this image using three hues and three colors of each hue is shown in Table 1.

II. Imaging System

The coherent imaging infrared radar testbed constructed at Lincoln Laboratory produces 128 pixel by 128 pixel digital images with a 12 mrad x 12 mrad field-of-view. Each pixel in the image has a digital intensity value between 0 and 255 counts. The 128 by 128 range matrix contains the range increment beyond the start of a variable range gate. Each digital count corresponds to a range increment of 9m, thereby providing a maximum range gate width of 2.3 km. Range and intensity data are recorded on digital tape for off-line image processing.

III. Range/Intensity Color Mapping

A. Intensity Map

The algorithm developed for producing a quasi-three-dimensional display of images obtained with the infrared radar operates in the following manner. First, a histogram (frequency of occurrence vs. intensity) is formed of the data in the image intensity matrix $I(i, j)$, where i, j denotes the i, j^{th} pixel. The mode and standard deviation of this histogram are calculated and used to define an empirically derived threshold intensity value

$$T = (\text{Mode}) + k\ (\text{Standard deviation}) \qquad (1)$$

where $0.1 \leq k \leq .25$

TABLE I

RANGE INTENSITY COLOR MAP

Intensity Value	Range Value		
	0 to 3	4 to 7	8 to 11
0	Black	Black	Black
1 to 4	Dark Red	Dark Yellow	Dark Blue
5 to 8	Red	Yellow	Blue
9 to 12	Light Red	Light Yellow	Light Blue

Using the cumulative distribution function of the histogram (i.e., the probability that the intensity of an arbitrary pixel is less than or equal to a given value), pixels with an intensity in excess of threshold are mapped into a small number N of equiprobable bins.[3] Pixels whose intensity does not exceed the threshold are considered as noise and mapped into a zero intensity bin. The end result of these operations is a new image intensity matrix $I'(i, j)$ where

$$0 \leq (I' = \text{integer}) \leq N$$

The intensity thresholding described above is required because the digital peak detector used in the infrared radar recording system determines the value of the highest intensity occurring within the range gate and the apparent range of that highest intensity for each pixel regardless of whether the highest intensity is due to a true target return or system noise. Without thresholding low-intensity areas of an image would contain many noise points of random hues (noise spikes occur at random times and therefore at random apparent ranges). This degrades edge definition and overall image quality. The threshold defined by Eq. (1) is obtained by examining the effects of varying the threshold on a variety of images.

B. Range Map

The image range matrix $R(i, j)$ is analyzed to determine the maximum R_{MAX} and minimum R_{MIN} digital range values for which there are pixels with nonzero I' values. Next, the range data are linearly mapped into a small number (H) of new range bins. That is, for each pixel a new range value

$R'(i, j)$ is calculated according to the relation

$$R' = \begin{cases} \text{integer part } [H\,(R - R_{MIN}) \,/\, (R_{MAX} - R_{MIN}) + 1], & \text{if } R_{MIN} \le R < R_{MAX} \\ H & \text{, if } R = R_{MAX} \end{cases} \tag{2}$$

where

$$1 \le (R' = \text{integer}) \le H$$

C. Display Map

Finally, a display value matrix $P(i, j)$ is calculated according to the relation

$$P(i, j) = \begin{cases} 0 & \text{, if } I'(i, j) = 0 \\ I'(i, j) + [R'(i, j) - 1]\,N, & \text{otherwise} \end{cases} \tag{3}$$

where

$$0 \le (P = \text{integer}) \le (N \cdot H).$$

The display value matrix is displayed through a pseudocolor video look-up table (with H hues, N apparent brightness levels of each hue, and zero level $P = 0$ = black) on the color display of a digital image processing system to produce a quasi-three-dimensional image of the original scene.

IV. Preliminary Results: Analysis and Imagery

In our initial work with range/intensity color mapping we have employed a 31-element video look-up table with 5 hues and 6 apparent brightness levels of each hue and a Ramtek GX-100B Graphic Display System interfaced to an IBM 370/168 for displaying images. The video look-up table is documented in Table II.

TABLE II

RANGE INTENSITY VIDEO LOOK-UP TABLE

Display Value	Color	Color Gun Intensity Red	Green	Blue
0	Black	0	0	0
1	Darkest Red	5	1	1
2	↓	6	1	1
3		8	2	2
4		10	3	3
5		12	3	3
6	Lightest Red	15	6	6
7	Darkest Yellow	7	5	1
8	↓	9	7	1
9		10	9	2
10		10	12	4
11		13	14	6
12	Lightest Yellow	14	15	8
13	Darkest Green	0	4	1
14	↓	0	7	1
15		0	10	3
16		0	13	5
17		0	14	7
18	Lightest Green	3	15	9
19	Darkest Blue	0	0	5
20	↓	0	2	8
21		0	4	10
22		0	6	12
23		0	9	14
24	Lightest Blue	0	11	15
25	Darkest Purple	6	2	6
26	↓	7	2	8
27		9	3	11
28		10	6	12
29		11	8	14
30	Lightest Purple	13	10	15

In Figs. 1 - 3 we show, respectively, a telephoto picture, a black-and-white intensity-only radar image, and a range/intensity color-mapped radar image of the Lincoln Laboratory Flight Facility at L.G. Hanscom Field in Bedford, Massachusetts. It should be noted that the telephoto pictures shown in this report were not taken on the same day as the radar images. In addition, both radar images represent a single frame of radar data. Several things are immediately evident from an examination of these pictures. The apparent quality of the image processed with range/intensity mapping is superior to the unprocessed radar image. The comparison, however, is somewhat misleading because the range/intensity processing algorithm contains an intrinsic histogram modification process.[3] Had the unprocessed image been subjected to the same histogram modification, it would have looked somewhat better although still not as good as the range/intensity mapped image.

The Lincoln Flight Facility is 2.7 km from the radar while the buildings in the foreground are roughly 1.7 km distant. This is not at all obvious from the black-and-white image but can be readily deduced from the processed image when one knows that the range gate spans values from 1.67 km to 2.9 km. That is, the range/intensity algorithm does produce an image with a three-dimensional quality. Finally, the color contrast tends to enhance the perception of small nearby objects (such as the utility wires running across the center of the picture) which are imaged against a more distant background. This should prove very useful in an obstacle avoidance system.

Figs. 4 - 6 show a telephoto picture, a black-and-white intensity-only radar image, and a processed radar image of the control tower and a hangar at

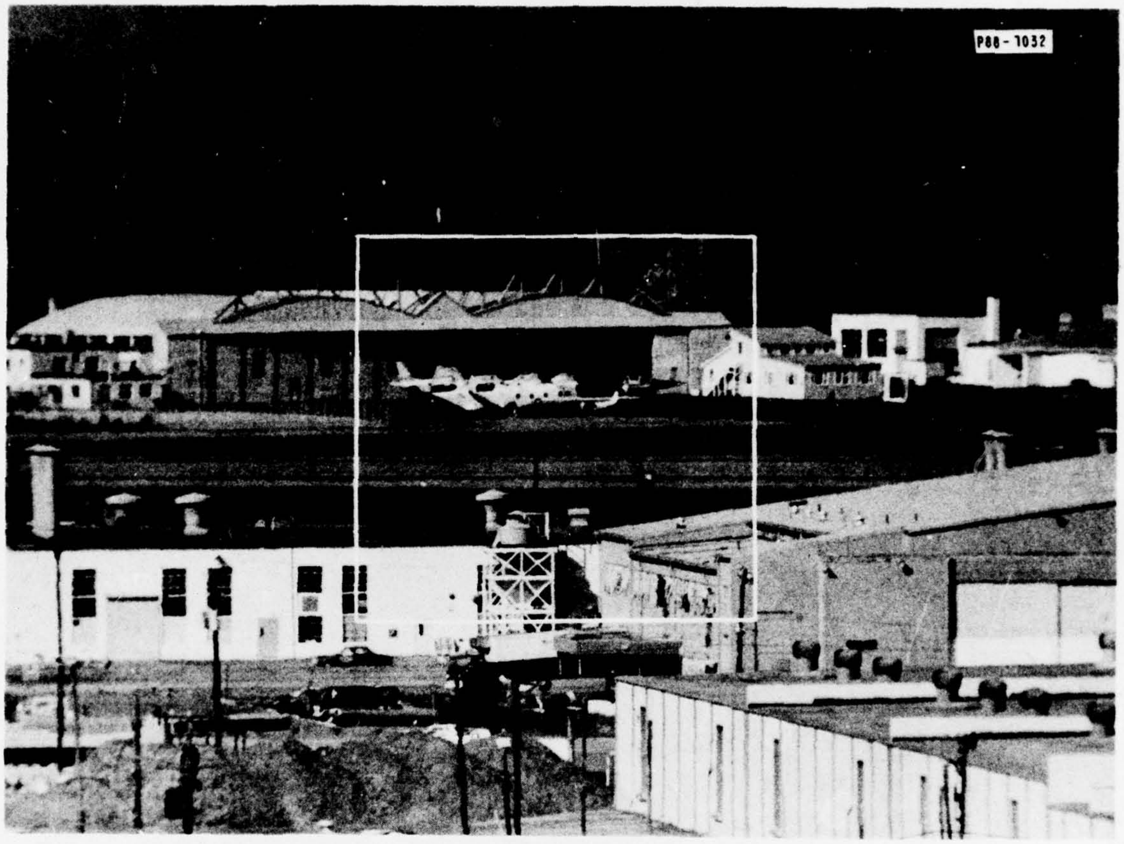

Fig. 1. Telephoto picture of the Lincoln Laboratory Flight Facility at Hanscom Field. Subsequent radar images cover the field-of-view outlined in white.

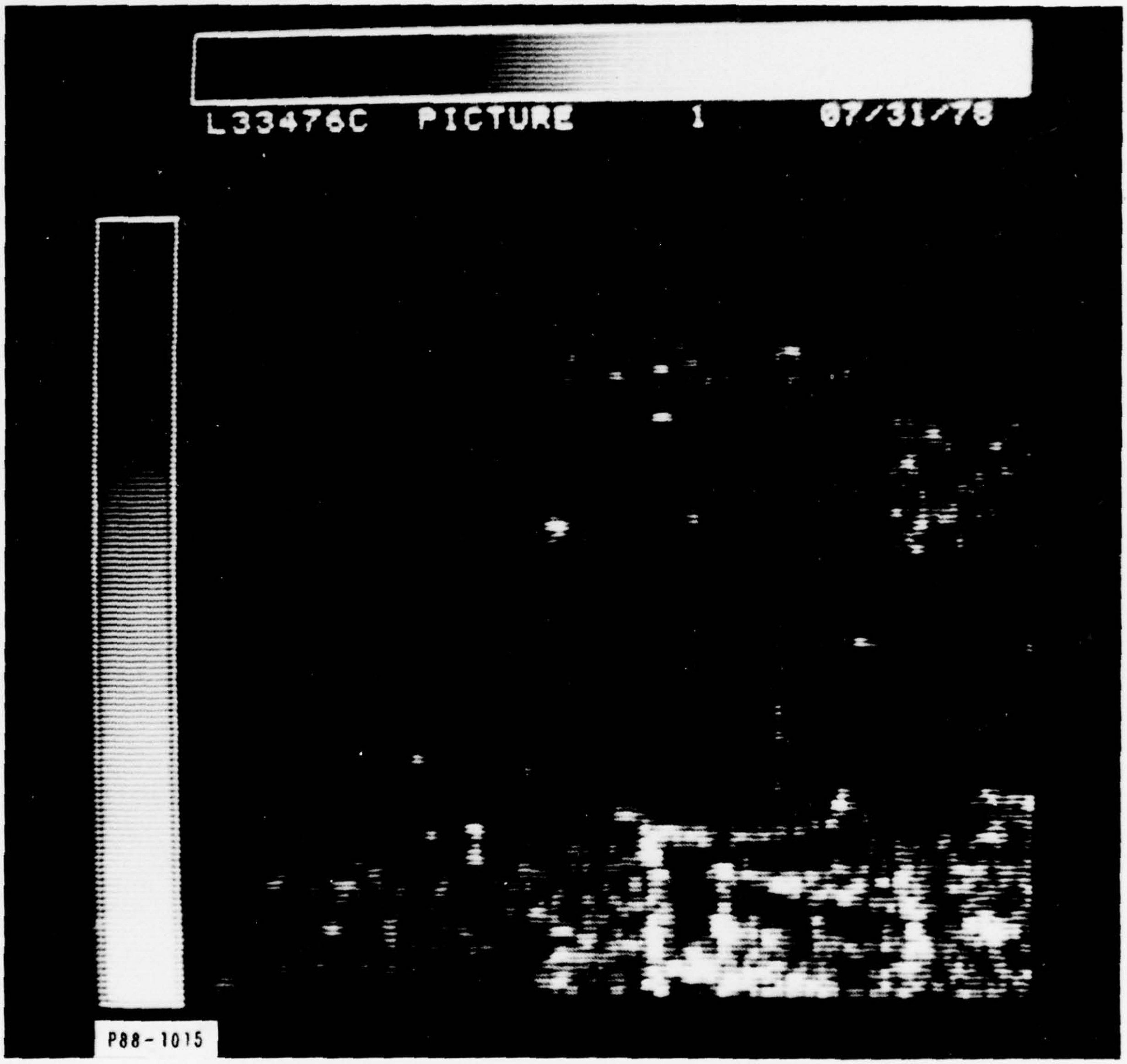

Fig. 2. Single-frame black-and-white intensity-only radar image of the Lincoln Flight Facility.

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Fig.3. Single-frame range/intensity color-mapped radar image of the Lincoln Flight Facility. The minimum and maximum ranges depicted are 1.67 km and 2.9 km, respectively.

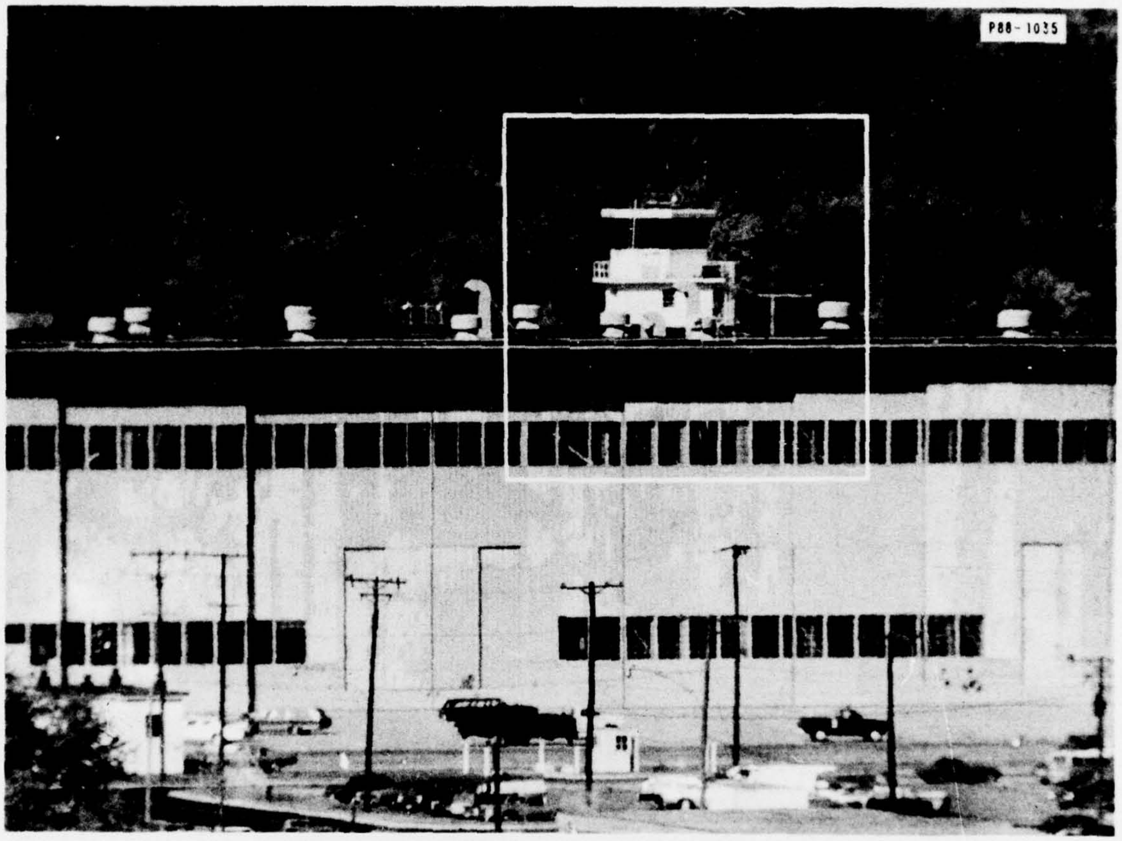

Fig. 4. Telephoto picture of the control tower at Hanscom Field. Subsequent radar images cover the field-of-view outlined in white.

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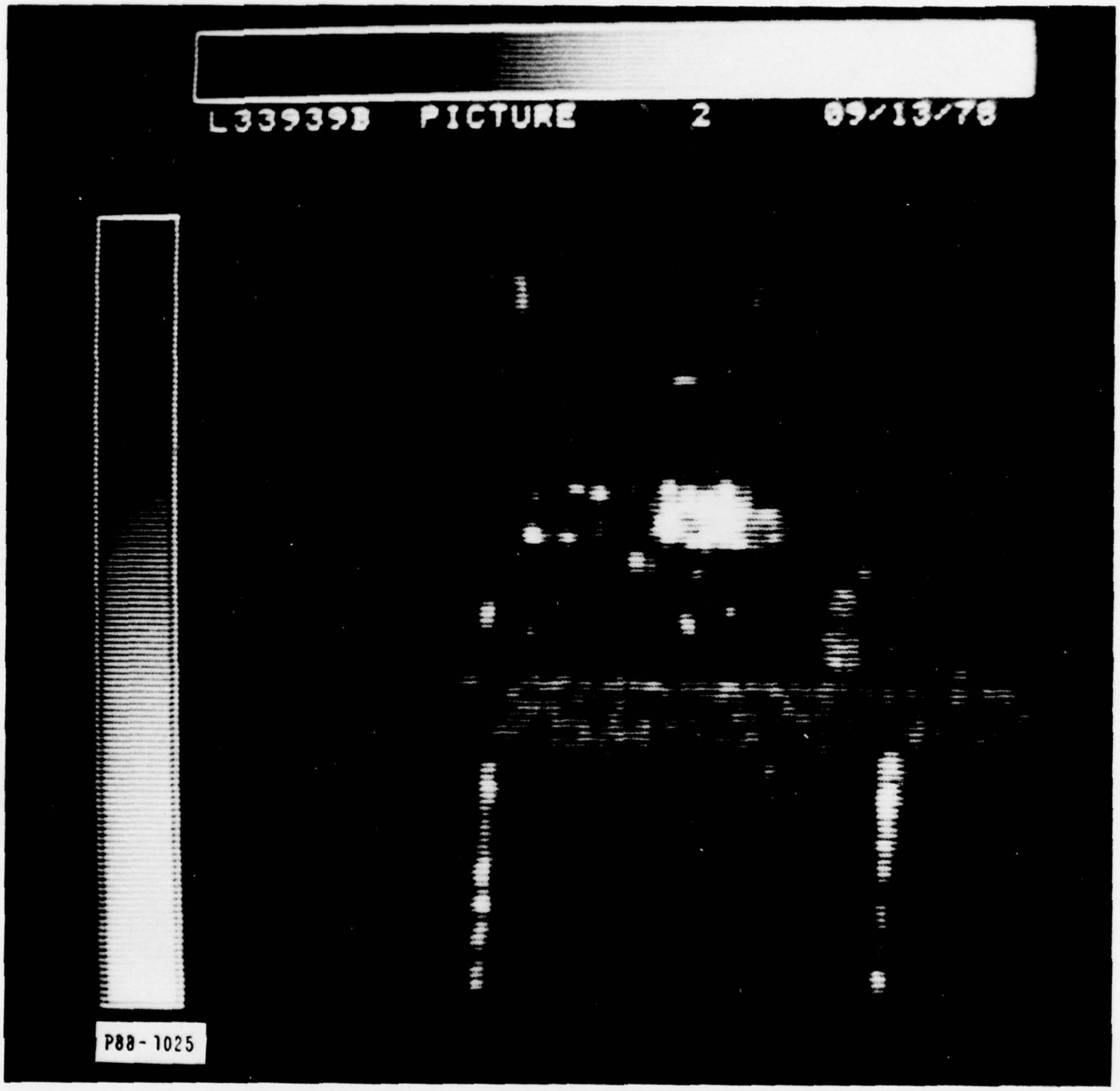

Fig. 5. Eight-frame average black-and-white intensity-only radar image of the control tower.

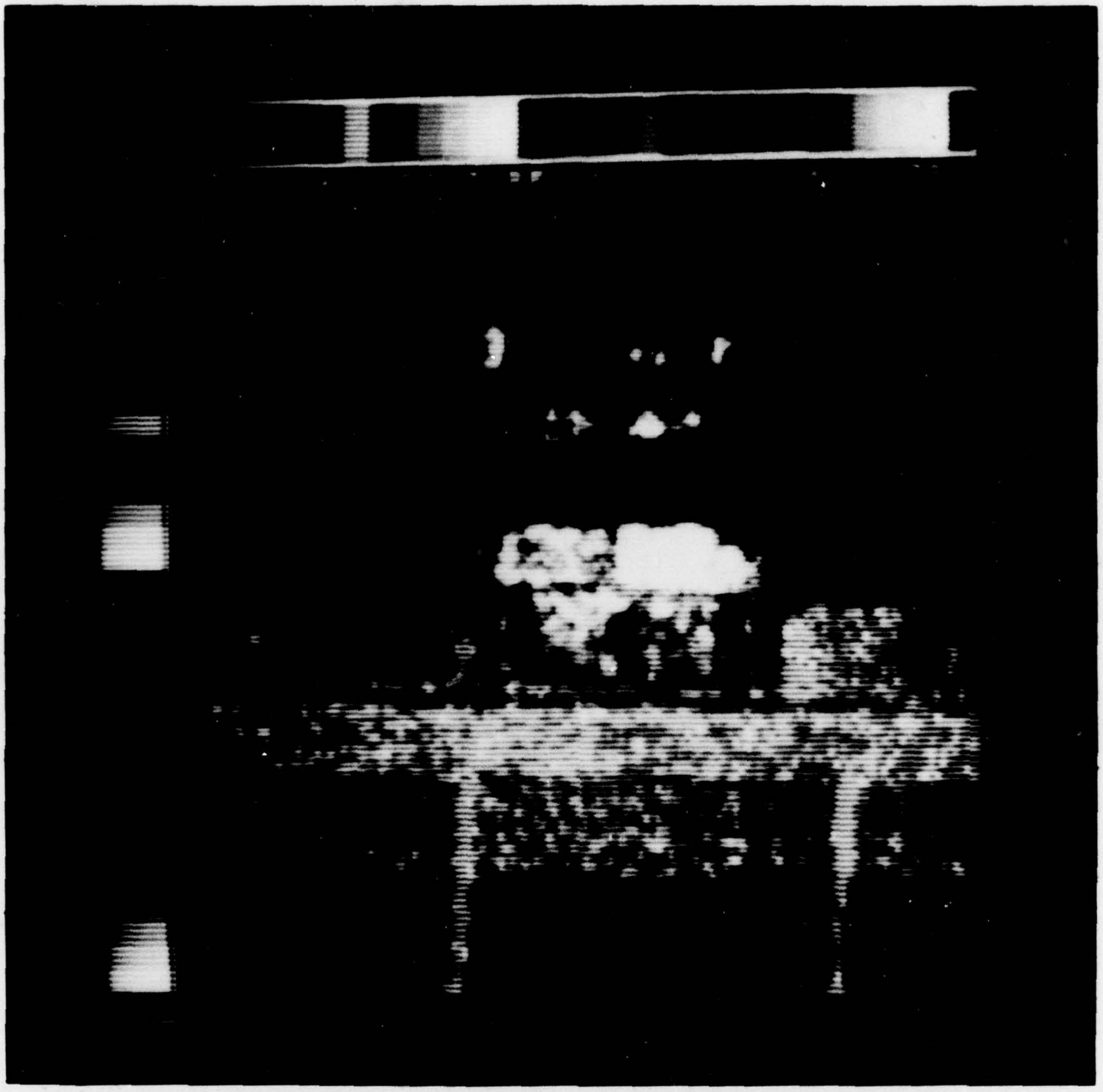

Fig.6. Eight-frame average range/intensity color-mapped radar image of the control tower. The minimum and maximum ranges depicted are 1.66 km and 2.60 km, respectively.

Hanscom Field. In this instance the processed image was the average of eight separate frames of intensity data and the corresponding eight frames of range data. Since the range/intensity algorithm needs only a range matrix and an intensity matrix as inputs, any amount of preprocessing can be performed before the algorithm is applied. This set of images also illustrates the three-dimensional quality of processed images, since the control tower is in actuality approximately 200 m farther away from the radar than is the hangar. This is immediately obvious from the processed image.

Figs. 7 - 11 show a telephoto picture, a single-frame black-and-white intensity-only radar image, a single frame range/intensity image, an eight-frame average black-and-white intensity only radar image, and an eight-frame average range/intensity image of a number of buildings at Hanscom Field. These images serve to indicate the ability of the algorithm to improve the clarity of highly-cluttered images as well as its ability to emphasize obstacles such as telephone wires.

Figs. 9 and 11 also demonstrate the adaptive character of the algorithm with respect to range. The R_{MAX} and R_{MIN} values of the single-frame and eight-frame average images differ significantly. As a result, the utilization of the color scale is different in the two images. Range adaptivity optimizes the use of the finite number of hues incorporated into the video look-up table. However, in an airborne system it is probably desirable to have each hue deleted from the algorithm by assigning fixed values to R_{MAX} and R_{MIN} instead of allowing the program to adaptively determine them. Furthermore, fixing R_{MIN} and R_{MAX} reduces the computation required, an important consideration in an airborne system.

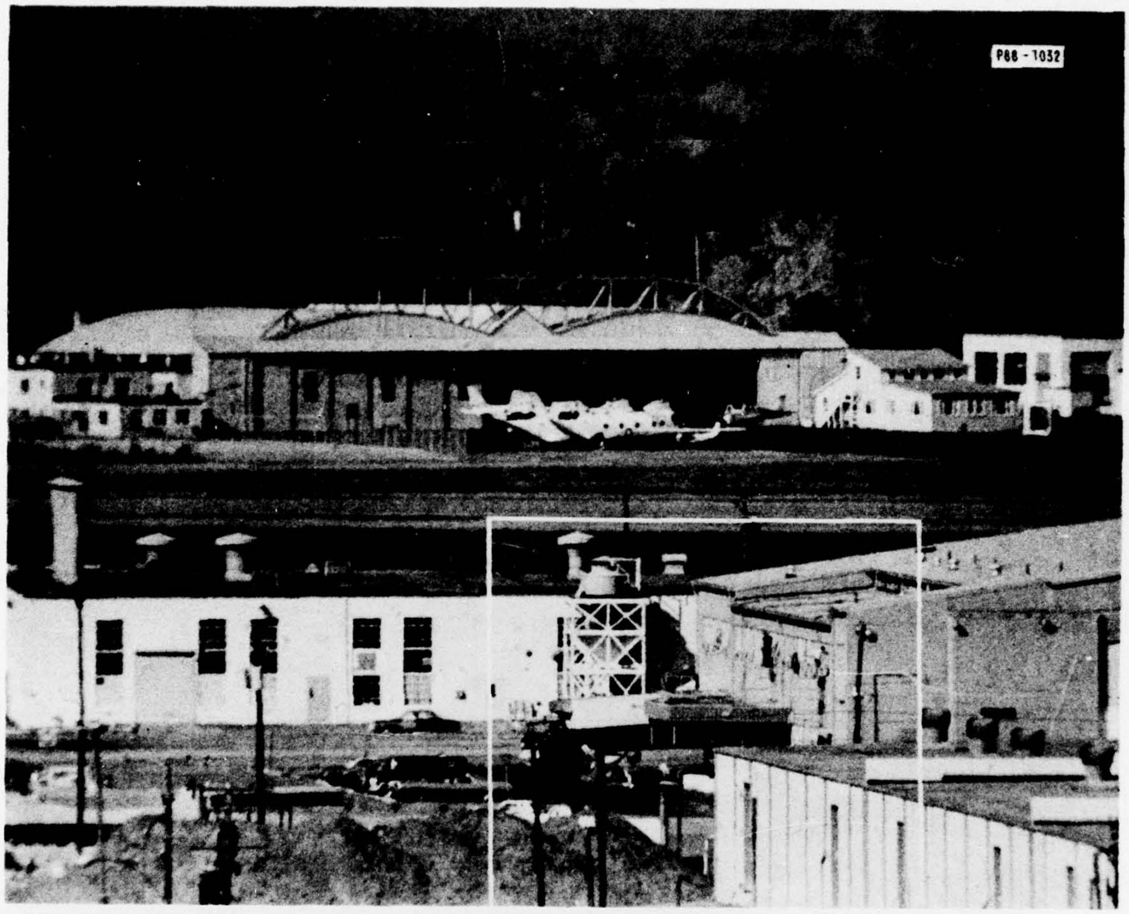

Fig. 7. Telephoto picture of buildings at Hanscom Field. Subsequent radar images cover the field-of-view outlined in white.

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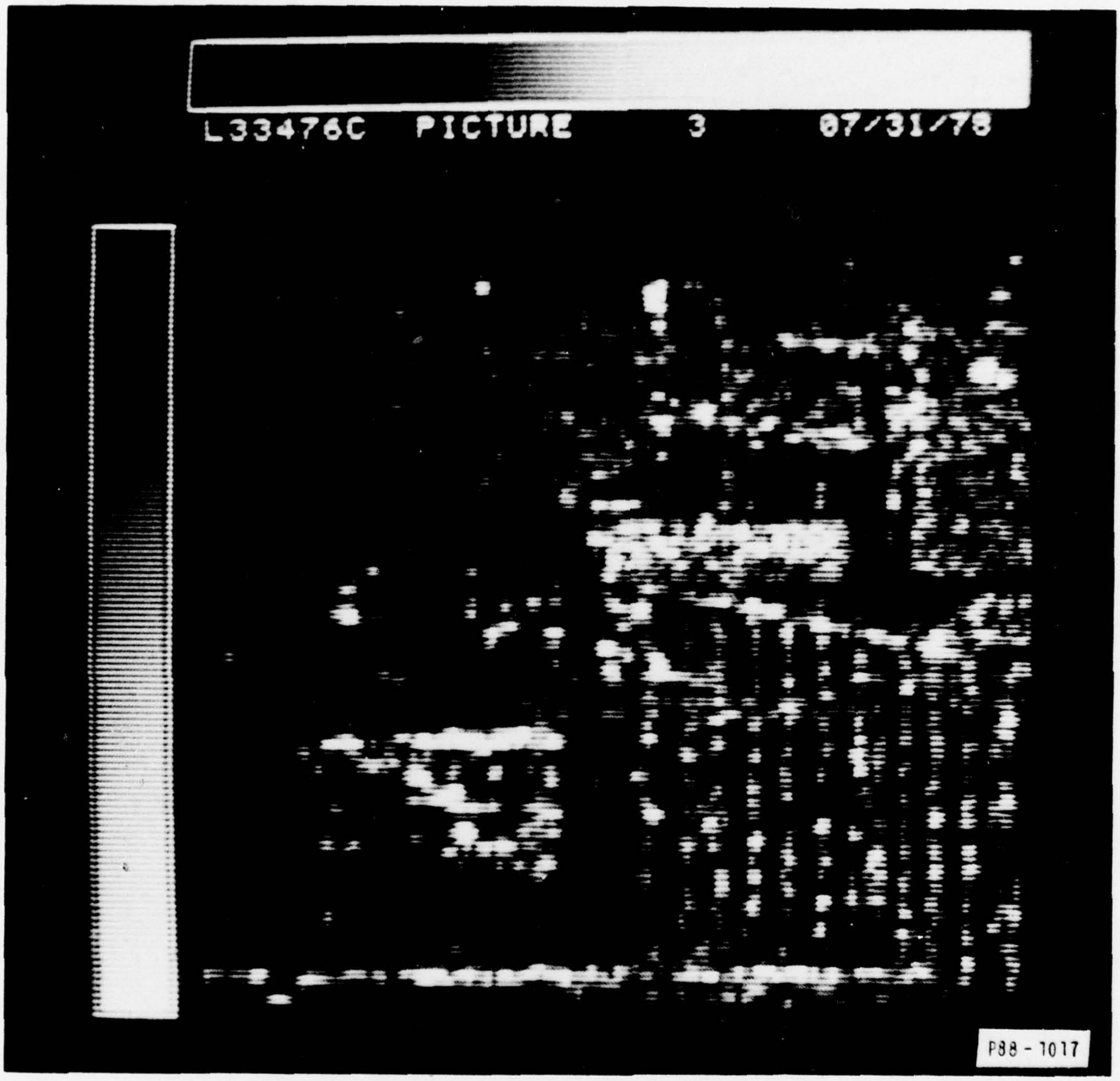

Fig. 8. Single-frame black-and-white intensity-only radar image of buildings at Hanscom Field.

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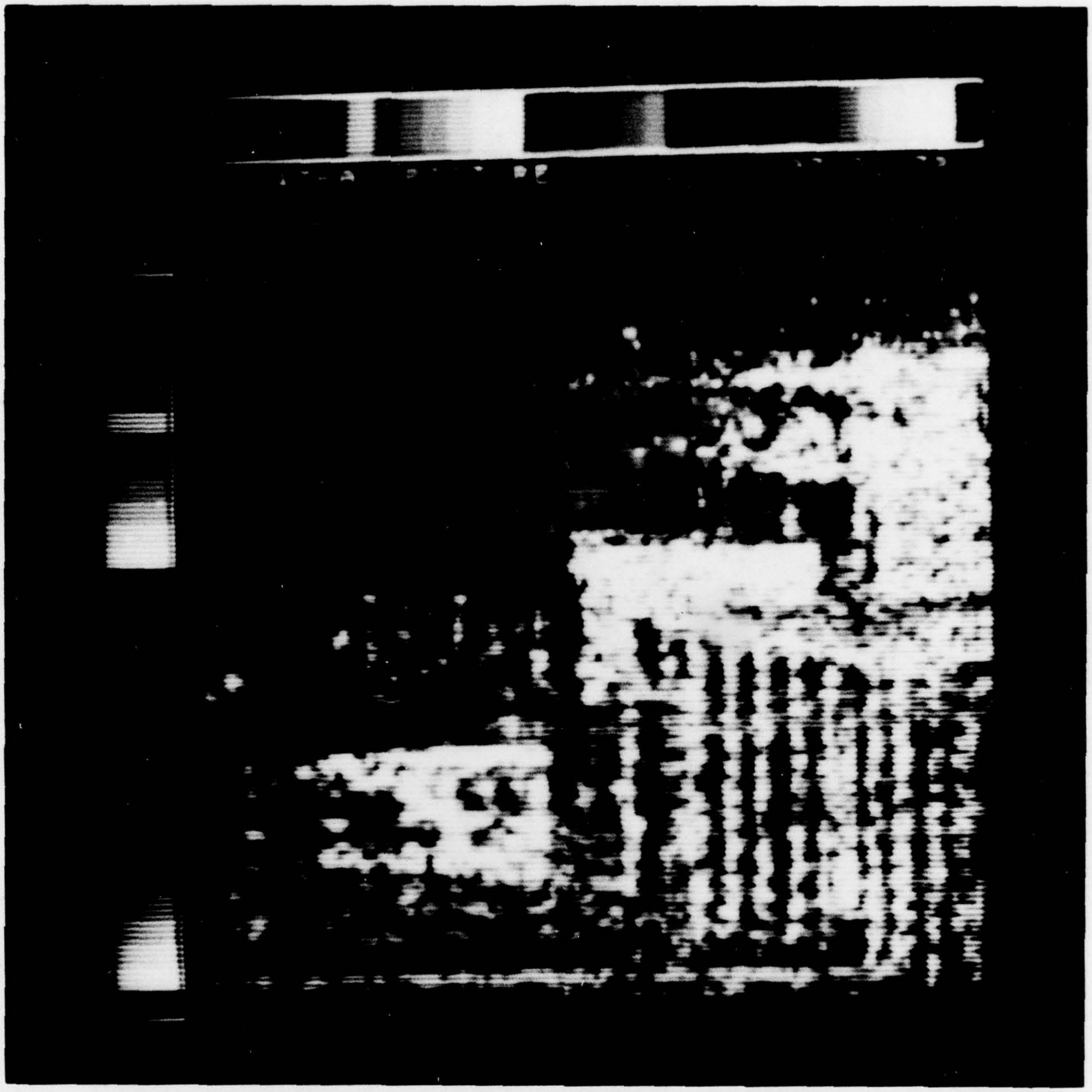

Fig.9. Single-frame range/intensity color-mapped radar image of buildings at Hanscom Field. The minimum and maximum ranges depicted are 1.21 km and 2.45 km, respectively.

V. Proposed Modifications

There are a number of potentially beneficial modifications which can be made to the algorithm. One of these involves the histogram modification procedure. At the present time histogram modification is performed on every nonzero pixel after intensity thresholding. No attention is paid to the range information. However, because infrared radar returns suffer an inverse square law decrease in intensity as the range increases, the present histogram modification process tends to force returns from close ranges into the brightest colors of their hue and to force returns from far ranges into the darkest colors of their hues. The end result is a reduction in the effective contrast of the image. This situation can be remedied by performing the range quantization first and then performing the histogram modification process on each range bin separately. This will increase the effective contrast and remove the range dependence of the image intensity.

Another possible modification involves the method of removing system noise. In many cases, frame averaging of data may be desirable. In that case, a standard deviation filter may be implemented to replace the intensity thresholding. If M frames of data are available, then for each pixel i, j the standard deviation σ_M of the M range values is calculated and compared with the expectation value σ_o of the standard deviation for returns due solely to random noise. Since range returns due to noise are uniformly distributed within the range gate

$$\sigma_o = (R_{MAX} - R_{MIN}) / \sqrt{12} \tag{4}$$

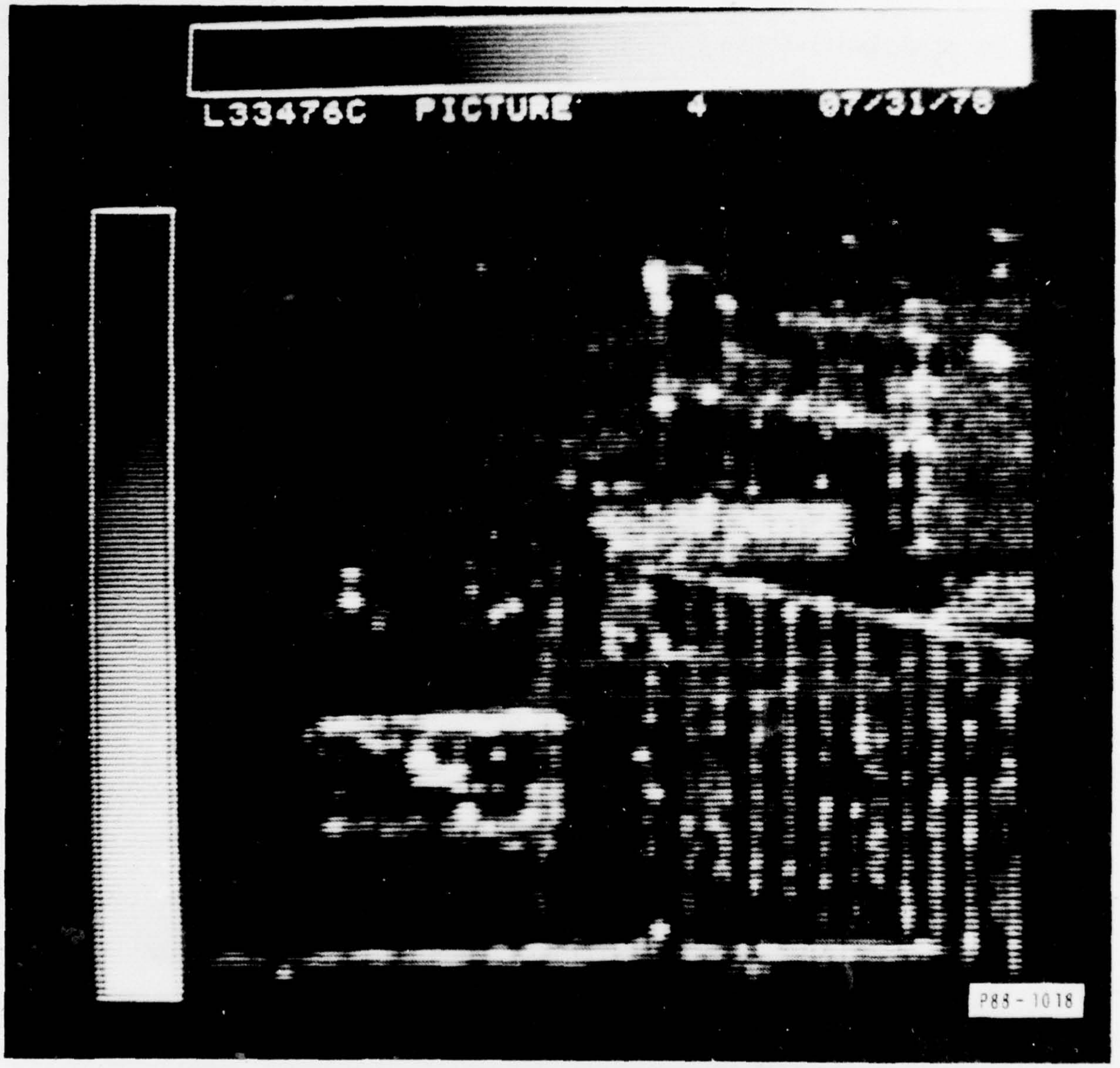

Fig. 10. Eight-frame average black-and-white intensity-only radar image of buildings at Hanscom Field.

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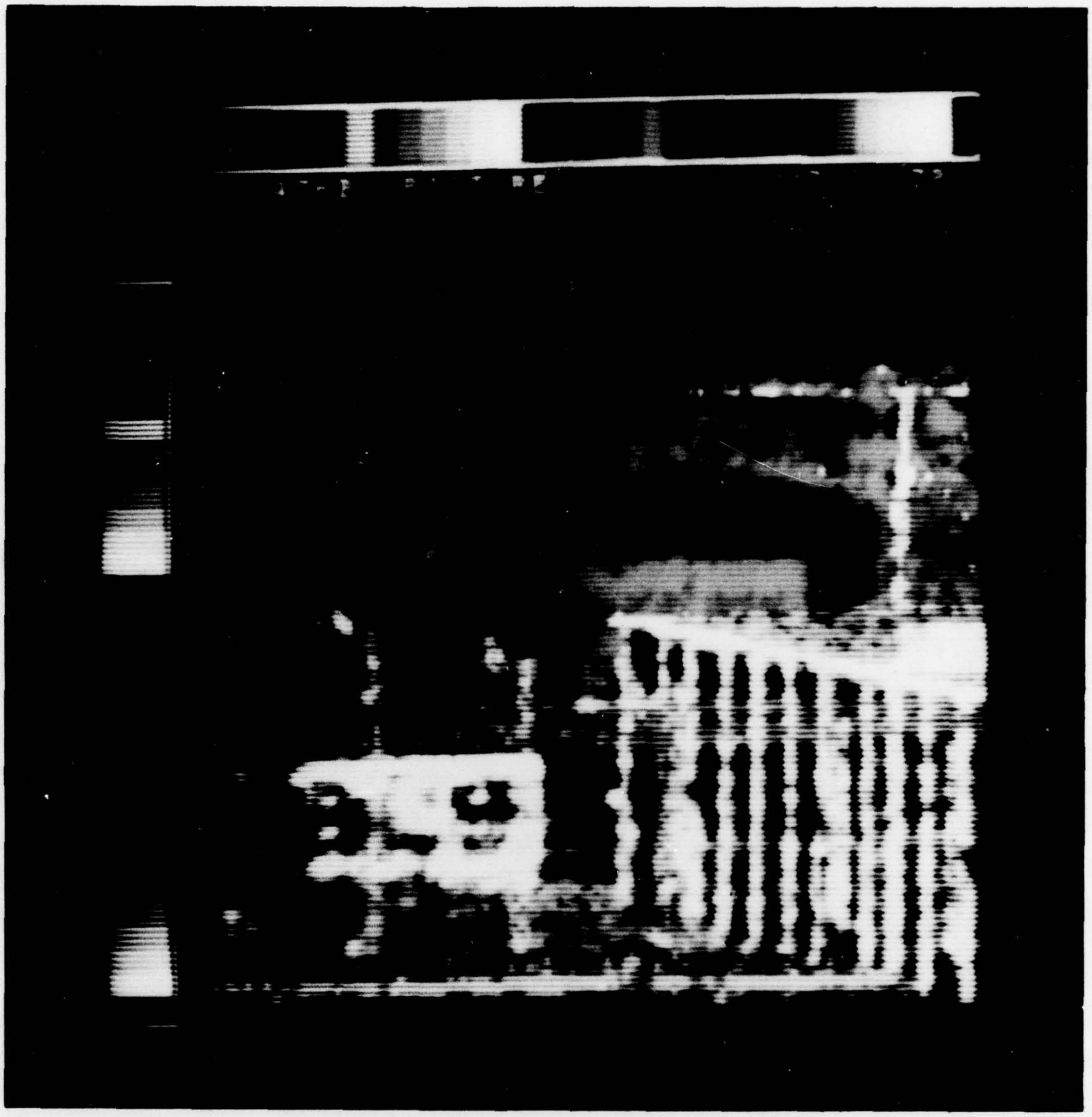

Fig.11. Eight-frame average range/intensity color-mapped radar image of buildings at Hanscom Field. The minimum and maximum ranges depicted are 1.21 km and 2.02 km, respectively.

If the range returns are due to pure noise, the measured values σ_M will be distributed about σ_o, while if the returns are due to signal alone (infinite signal-to-noise ratio), the σ_M will be identically equal to zero. For finite signal-to-noise ratios, the σ_M will be distributed between zero and σ_o. Therefore, if $\sigma_M < \varepsilon\sigma_o$ where ε is a factor between 0 and 1, the returns are assumed to be signal returns and the average range and intensity are stored in the appropriate matrices. Determining the optimum value for ε can be accomplished either empirically or from detection theory.[4] A standard deviation filter may prove to be a better discriminant against noise than the simple intensity thresholding.

An area requiring significant future effort is the development of video look-up tables with more hues and more apparent brightness levels. The five-hue video look-up table described in Table II is by no means optimum. It represents only an initial attempt at range/intensity color mapping that sufficed to demonstrate the viability of the concept. If more visually distinct hues can be incorporated into the video look-up table, the range resolution will be higher and the clarity that can be obtained in cluttered images will be incorporated into the table, the discrimination in target reflectivities will be higher and the image will be more visually pleasing. Clearly, however, there are practical limits to the size of the table and there are perceptual limits as well. That is, as the number of hues increases, it will be harder to produce a large number of apparent brightness levels of each hue which are readily distinguishable as belonging to that hue and not to a neighboring hue. The problem is further compounded by the limited brightness of color cathode ray tubes and the extreme variations in ambient light which may be encountered in practical applications. A significant amount of effort will be needed to obtain a perceptually optimum video look-up table.

VI. Conclusions

In conclusion, we have demonstrated that range/intensity color mapping is a viable technique for producing quasi-three-dimensional displays of infrared radar images. The implementation of this technique in an airborne system would require relatively simple digital electronics and is well within the scope of today's technology.

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By mapping range information into different hues and intensity information into different apparent brightness levels of each hue on a color display, a three-dimensional quality can be imparted to infrared radar images. A computer algorithm for implementing this range/intensity color mapping is described and several infrared radar images demonstrating the technique are presented. Possible improvements to the current algorithm and areas requiring additional study are also discussed.

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